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MAY 80 D HERRON, L M WINDINGLAND, D C HITTLE
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(BLAST Validation)

LEVEL II

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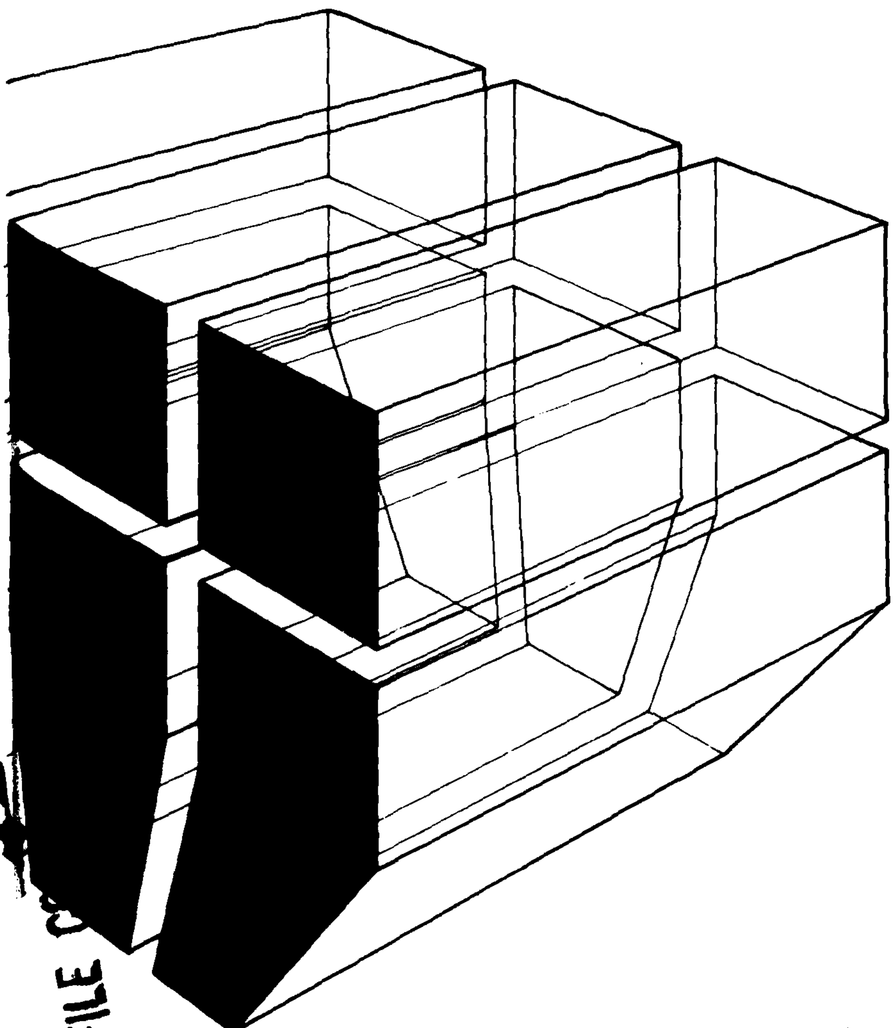
COMPARISON OF BUILDING LOADS ANALYSIS AND SYSTEM THERMODYNAMICS (BLAST) COMPUTER PROGRAM SIMULATIONS AND MEASURED ENERGY USE FOR ARMY BUILDINGS



by
D. Herron
L. Windingland
D. Hittle

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This report describes an analysis of actual measured energy consumption vs energy consumption simulated by the Building Loads Analysis and System Thermodynamics (BLAST) computer program. A dental clinic and a battalion headquarters and classroom building were modeled; comparisons of the BLAST output using onsite weather and measured energy consumption data are made for the two buildings. The report includes tables and figures describing how well the BLAST program calculates the

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building's internal electrical load and, by comparing simulation results with measured values, predicts the building's cooling load and chiller performance as described by the chiller electrical energy consumption.

FOREWORD

This work was performed for the Directorate of Military Programs, Office of the Chief of Engineers (OCE), under Project 4A762731AT41, "Design, Construction, and Operation and Technology for Military Facilities"; Technical Area G; Work Unit 001, "BLAST Validation." Mr. Ed Zulkofske, DAEN-MPE-E, was the OCE Technical Monitor.

This work was performed by the Energy and Habitability (EH) Division of the U.S. Army Construction Engineering Research Laboratory (CERL). Mr. R. G. Donaghy is Chief of EH. Much work that contributed to this effort was performed under contract DACA 80-78-R-0004. Appreciation for their support during data collection is expressed to Yandell and Hiller, Inc., Fort Worth, TX.

COL Louis J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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SIMULATIONS AND MEASURED ENERGY USE FOR ARMY BUILDINGS

1 INTRODUCTION

Background

The Building Loads Analysis and System Thermodynamics (BLAST) computer program predicts hourly space heating and cooling requirements, simulates hourly fan system performance, and simulates hourly performance of conventional heating and cooling, solar energy, or total energy systems for new and existing buildings.[1] The program has been field tested and was released for general use in December of 1977. The BLAST program is considerably more powerful, accurate, and provides more information to the designer than hand calculation methods. Consequently, it is now widely used by the Army, Department of Defense, other Federal agencies, and private architect/engineers in the United States, Europe, and Canada to determine both expected energy use in new and existing buildings, and to help optimize building and energy system design.

Although extensive BLAST field tests have proved the program to be accurate and usable, a study comparing BLAST simulation results to measured field data was considered desirable. Such a study could identify weaknesses in the BLAST program and help define important building parameter inputs. Therefore, the U.S. Army Construction Engineering Research Laboratory (CERL) was asked to analyze and compare actual measured data against BLAST-predicted energy consumption for two Army buildings in an attempt to verify the prediction capabilities of the BLAST program.

Objective

The objective of this report is to compare the results of BLAST simulations (using actual, onsite weather data) with measured building energy consumption data.

[1] D. C. Hittle, The Building Loads Analysis and System Thermodynamics (BLAST) Program, Version 2.0, Users Manual, Vols I and II, Technical Report (TR) E-153/ADA072272 and ADA0722730; The Building Loads Analysis and System Thermodynamics (BLAST) Program Input Booklet, TR E-154/ADA072435 (U.S. Army Construction Engineering Research Laboratory [CERL], June 1979).

Approach

The following approach was used to perform this comparative study:

1. Two Army buildings were selected from among some 100 Army buildings participating in an energy monitoring project designed to measure actual, onsite energy-use and climate data.

2. Construction drawings for the selected buildings were obtained; information from these drawings was then used to prepare input for the BLAST simulation.

3. Additional building and heating, ventilating, and air-conditioning (HVAC) system information was collected, as necessary, by onsite measurement and observation.

4. Hourly weather data and concurrent building energy-use data were obtained from onsite instruments.

5. BLAST simulations were performed and comparisons made between predicted energy use and actual energy use for the selected buildings.

6. Results were analyzed to determine the extent of agreement between the BLAST simulation and measured energy use and to determine the cause, if any, of disagreement between BLAST and measured building energy use.

2 DISCUSSION

Background

From 1976 to 1978, an Army-sponsored energy monitoring project measured hourly heating, cooling, and electrical consumption data for more than 100 Army buildings at different installations throughout the continental United States. Hourly climatic data, including ambient temperature, dew point temperature, wind speed, wind direction, barometric pressure, and solar radiation were also collected using appropriate sensors, electronic interface devices, and recorder systems.[2] However, only a few of these 100 buildings were monitored closely enough to allow their individual energy use, including heating and cooling requirements, to be identified. It was from among the buildings with measurable individual data that CERL selected two representative Army buildings for the BLAST prediction/comparison study.

Building Selection

The first building selected was a single-story, 18-chair dental clinic with laboratory at Fort Hood, TX. Figures 1 and 2 show the floor plan and typical wall, roof, and floor sections of the dental clinic, respectively. The clinic was built in 1968 and has a gross area of 9384 sq ft (872 m^2). It is constructed of block and brick and uses a steel truss roof system and built-up roof. It has an exterior wall area of 4050 sq ft (376 m^2), of which approximately 340 sq ft (32 m^2) are windows or glass doors. The clinic is served by a multizone air-handling system with 10 distinct building zones. A reciprocating chiller and an air-cooled condenser package (60-ton capacity) supply the chilled water to the multizone system, and a gas-fired hot water boiler is used for heating. The clinic's hourly electrical consumption and natural gas usage are being metered under the Army's energy monitoring project.

The second building chosen was a battalion headquarters and classroom building built in 1974 at Fort Carson, CO. This one-story structure has a ground floor area of 18,907 sq ft (1757 m^2) and a basement area of 3330 sq ft (310 m^2). The building is 259 ft (79 m) long, 73 ft (24 m) wide, and has an exterior wall area of 8235 sq ft (765 m^2), of which 933 sq ft (87 m^2) are windows and glass doors. This building is

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[2] L. M. Windingland and B. J. Sliwinski, Fixed Facilities Energy Consumption Investigation -- Initial Energy Data, Interim Report (IR) E-120/ADA051074 (CERL, January 1978); L. Windingland, B. Sliwinski, and A. Mech, Fixed Facilities Energy Consumption Investigation Data Users Manual, IR E-127/ADA052708 (CERL, February 1978); and B. Sliwinski, D. Leverenz, and L. Windingland, Fixed Facilities Energy Consumption Investigation -- Data Analysis, IR E-143/ADA066513 (CERL, February 1979).

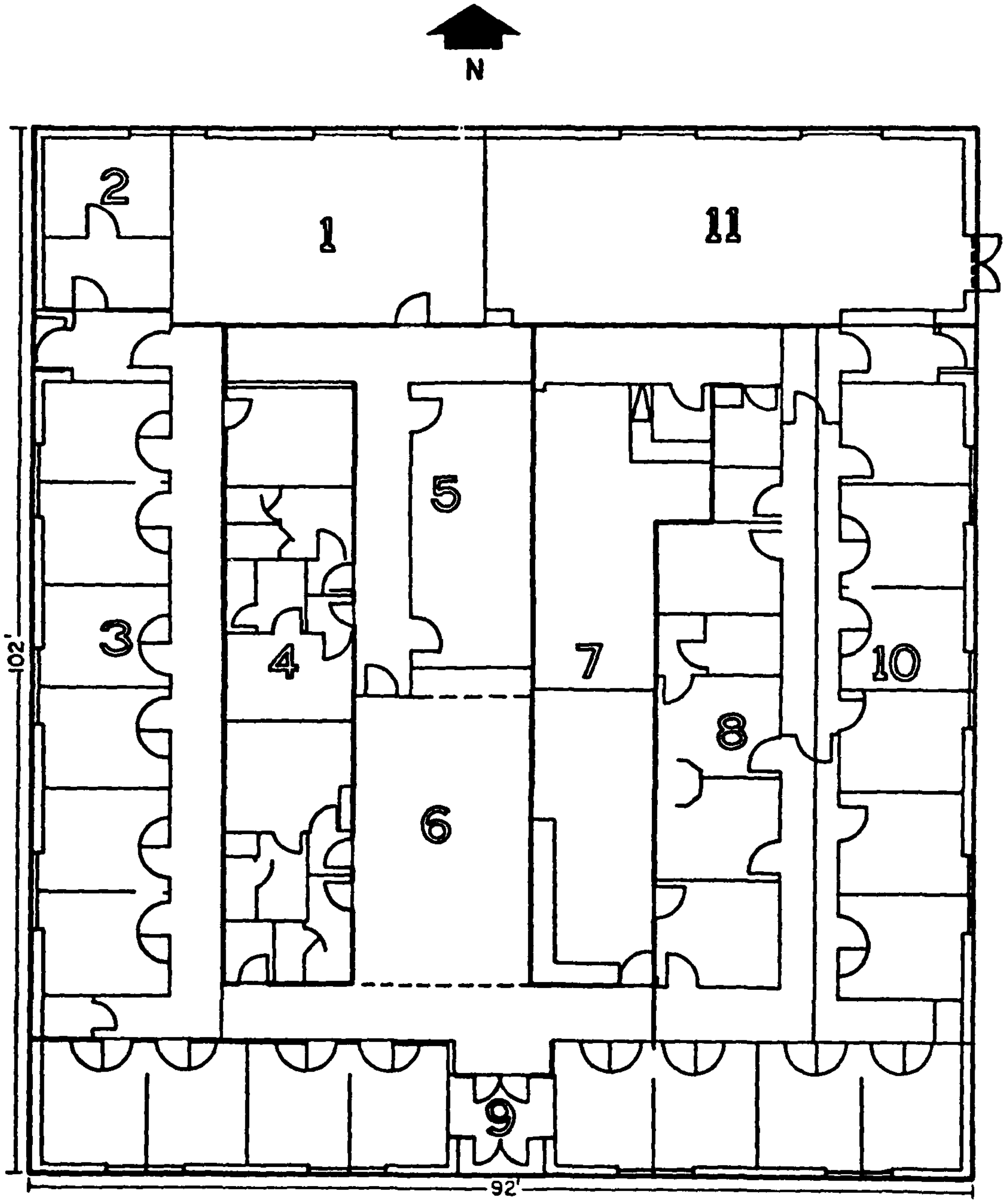

Figure 1. Floor plan -- dental clinic.

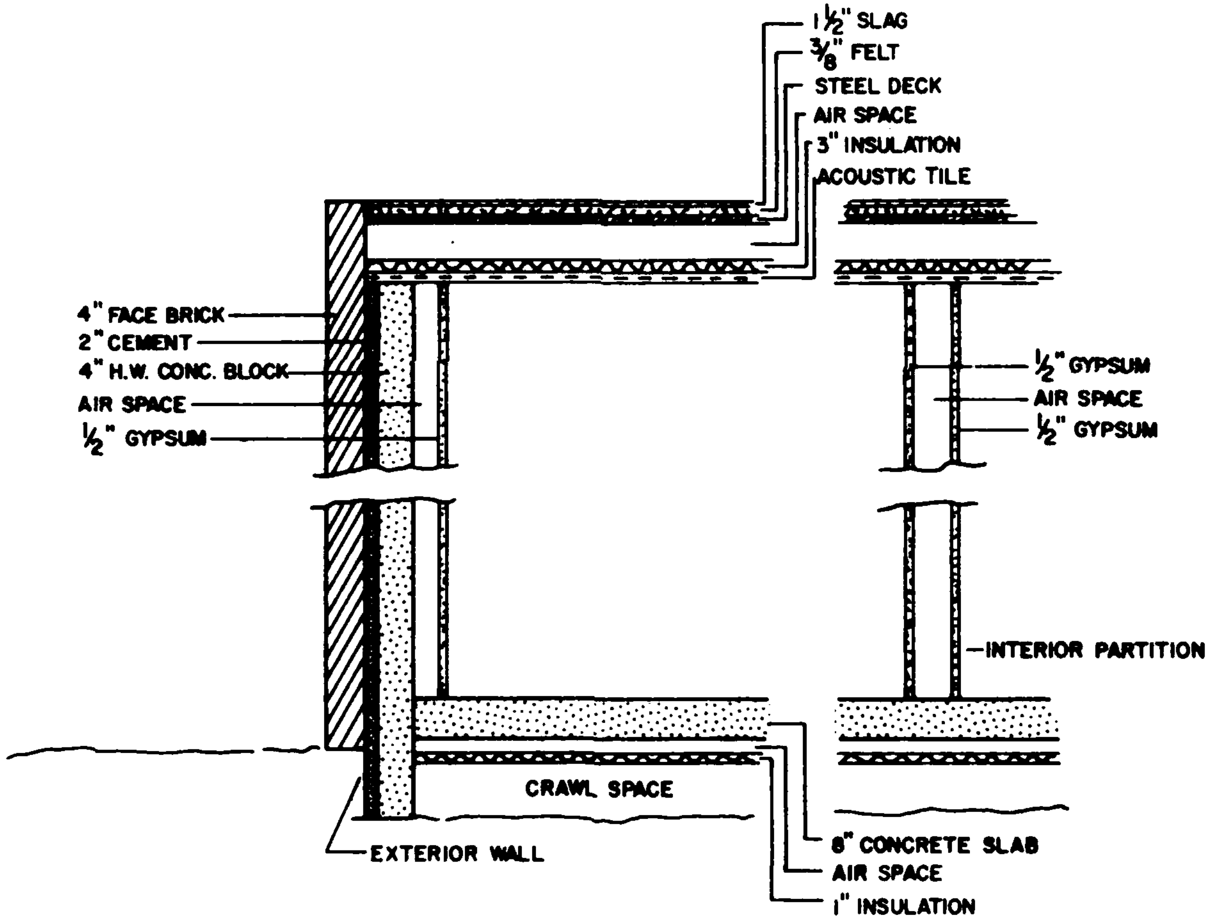

Figure 2. Wall, floor, and ceiling detail -- dental clinic.

served by a multizone air-handling system which receives its hot and chilled water from a remote central boiler/chiller plant. Energy monitoring project data being measured for this building include hot and chilled water flow rate, supply and return temperatures, and electric energy use. Figure 3 shows the building's floor plan. Figure 4 shows typical wall, roof, and floor sections.

Construction Drawings

The as-built construction drawings for each of the buildings selected for analysis were obtained from Facilities Engineers and field verified. These drawings included floor plans, architectural details (including wall, roof, and floor construction details), electrical plans, mechanical plans, equipment lists and schedules, and HVAC control diagrams. The input decks for the BLAST computer program were prepared using some of the information contained on the as-built construction drawings; other information required for the input decks was gathered by a contractor (see the following section).

Building and HVAC System Data

A field survey and onsite measurements of system parameters were necessary to prepare accurate input for the BLAST program. A contractor, Yandell and Hiller, Inc., Fort Worth, TX, collected these additional field data; the contractor's data collection activities were divided into three tasks:

1. Task 1 -- Familiarization With Buildings. The contractor reviewed building drawings and made onsite visits to verify as-built drawings against the actual building. Particular emphasis was placed on building modifications; installed equipment capacities; verification of actual wall, roof, floor, and ceiling construction materials; equipment control strategies; and operating procedures.

2. Task 2 -- Building Survey. The contractor prepared and distributed an occupancy questionnaire which was analyzed to determine the building's occupancy profile (i.e., the number of occupants in the building, when they went to lunch, and when they left for the day). The contractor also observed the operation of the building, recording for short periods the number of times doors and windows were opened, exhaust fan operation, and other parameters so an estimate could be made of the building's air infiltration. In addition, the contractor determined the capacities of installed mechanical equipment and obtained manufacturer's specifications or data sheets for each piece of equipment in the building, including air-handling unit fans, heating and cooling coils, boilers and chillers, unit heaters, water heaters, exhaust fans, and HVAC system controls.

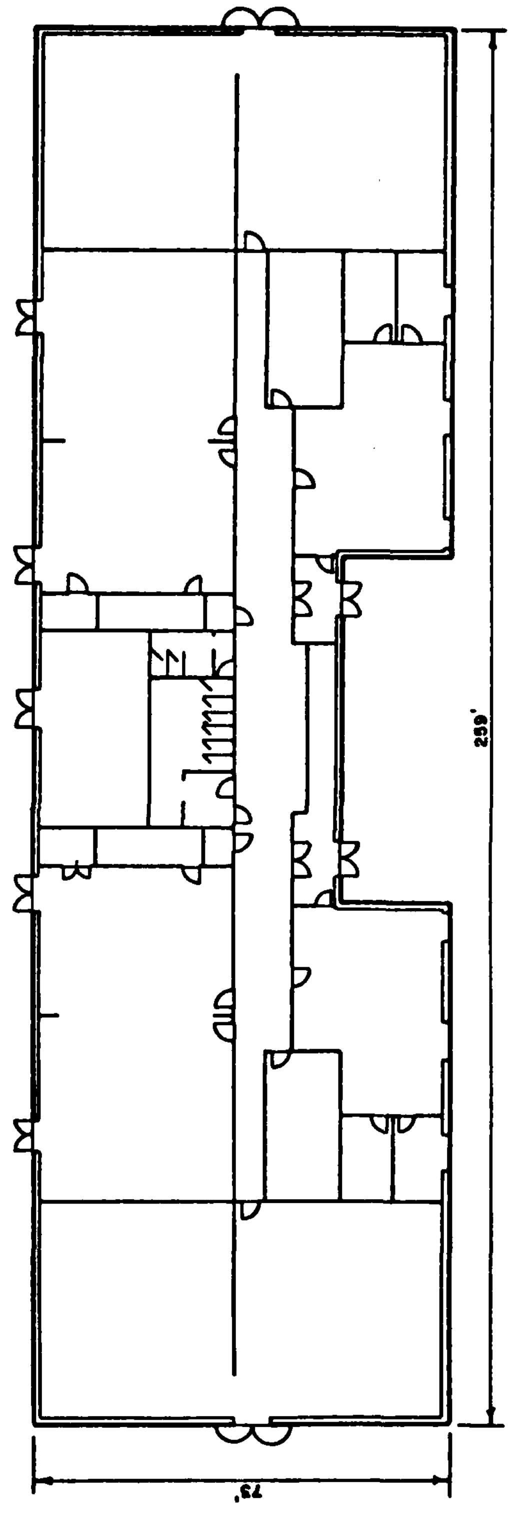

Figure 3. Floor plan -- battalion headquarters and classroom building.

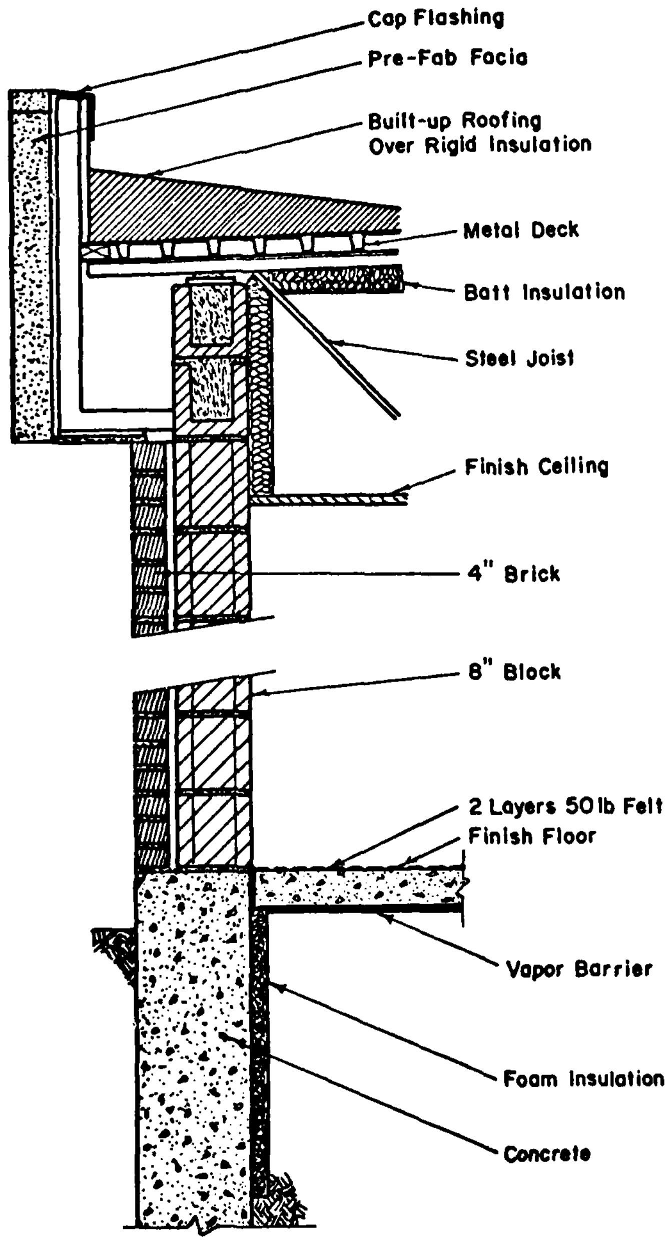

Figure 4. Wall, floor, and ceiling detail -- battalion headquarters and classroom.

3. Task 3 -- Data Monitoring. The contractor measured outside air quantities, return air quantities, total supply air flow, the supply air flow to each zone in the building, and air temperatures of both the hot and cold decks. In addition, each building's fan operating periods and full-load consumption were determined. Temporary electrical measuring devices were installed so the energy use of the heating and cooling system's components could be separated from the remaining electrical energy used within the building. The contractor also installed temporary recording devices to monitor the detailed energy performance of one zone in each building. Building HVAC system controls were checked to determine the actual sequence of operation and, where possible, controller set point and throttling ranges. Table 1 lists the items surveyed, method of monitoring, and frequency and duration of monitoring.

The data listed in Table 1 were continuously recorded for the dental clinic at Fort Hood between 24 June and 26 July 1978 and between 6 February and 4 March 1979. Data for the battalion headquarters and classroom building at Fort Carson were recorded between 4 August and 6 September 1978 and 9 to 24 March 1979.

Computer Simulation

BLAST input decks were prepared to simulate both the dental clinic and the battalion headquarters and classroom building using data from field surveys, contractor measurements, and as-built drawings. Actual onsite weather data were used. To insure the independent integrity of the BLAST simulations, data gathered under the Army's energy monitoring project were not inspected before or during BLAST input preparation.

Comparison of Actual and Simulated Results

Once the BLAST simulations were completed, the actual energy-use data were inspected for the same time period for which the simulations were performed. Data comparisons between simulated and measured data were then made for the entire period. Data comparisons were also made on an hourly basis to determine the agreement between BLAST-predicted and measured energy-use data. The hourly simulation data were examined to insure that cancelling errors did not result in unusually close agreement in total energy use for the simulation period. Additional BLAST simulations were performed with modified input based on measured data analysis when it could be clearly demonstrated that disagreement was caused by errors in the input data. A statistical analysis was then performed on the variances between the BLAST simulation and the actual energy use.

Table 1

BLAST Validation Input Data

Item Surveyed or Monitored	Collection Method	Number and Frequency of Sample	Duration Sample	Measuring Accuracy
Number of occupants	Questionnaire and survey	8 observations for both weekdays & weekend	2-4 days	±5%
Door & window openings	Physical survey	48 observations	2-4 days	±10%
Exhaust fan operation	Physical survey	24 observations	2-4 days	±10%
Zone				
Indoor temperature	Sensor	Continuous monitoring	2 each 2-week period	±1°F(±0.56°C)
Relative humidity	Sensor	Continuous monitoring	2 each 2-week period	±2%
Lighting & appliances	Sensor	Continuous monitoring	2 each 2-week period	±2%
Supply air temperature	Sensor	Continuous monitoring	2 each 2-week period	±2%
Supply volume	Rotating vane anemometer	12 measurements	2 different days each. period	±2%
Building				
Mixed air dew point temperature	Sensor	Continuous monitoring	2 each 2-week period	±1°F(±0.56°C)
Total fan supply volume	Pitot rack	Continuous monitoring	2 each 2-week period	±5%

*Volume is the volumetric airflow rate in cubic feet per minute.

Table 1 (Cont'd)

Item Surveyed or Monitored	Collection Method	Number and Frequency of Sample	Duration Sample	Measuring Accuracy
Return & outside air volume	Engineering calculations	Continuous monitoring	2 each 2-week period	±5%
Volume to each zone*	Pitot tube traverse	12 measurements	2 different days each period	±5%
Cold deck air temperature	Sensor	Continuous monitoring	2 each 2-week period	$\pm 1^{\circ}F(\pm 0.56^{\circ}C)$
Hot deck air temperature	Sensor	Continuous monitoring	2 each 2-week period	$\pm 1^{\circ}F(\pm 0.56^{\circ}C)$
Cold deck water temperature	Sensor	Continuous monitoring	2 each 2-week period	$\pm 0.5^{\circ}F(\pm 0.28^{\circ}C)$
Hot deck water temperature	Sensor	Continuous monitoring	2 each 2-week period	$\pm 0.5^{\circ}F(\pm 0.28^{\circ}C)$
Fan power	Sensor	Continuous monitoring	2 each 2-week period	±2%
Fan speed	Tachometer	1 observation	N/A	±2%
Mechanical equipment power	Sensor	Continuous monitoring	2 each 2-week period	±2%
Boiler "on-time"	Sensor	Continuous monitoring	2 each 2-week period	±2%
Water heater "on-time"	Sensor	Continuous monitoring	2 each 2-week period	±2%

3 ANALYSIS AND FINDINGS

Building Description -- Dental Clinic

The dental clinic was divided into 10 simulation zones which corresponded to the zones served by the clinic's multizone air-handling unit (Figure 1). Zone geometries and construction details of the walls, roof, and floor were determined from the construction drawings. The crawlspace was simulated to accurately model heat transfer through the floor.

Internal electrical load profiles for the clinic and the peak internal electrical demand (as supplied by the contractor) are shown in Figure 5. Peak electrical demand for each zone was estimated from a disaggregation of the peak internal building electrical demand. The occupancy profile for the building (Figure 6), zone peak occupancy (based on building-use patterns), and zone thermostat settings and control profiles were determined from contractor-supplied data.

Mechanical Systems -- Dental Clinic

Specific information about the mechanical system was obtained from HVAC control diagrams, control specifications, and measured or observed data. Design cooling coil parameters were obtained from the construction drawings. Design and part-load data for the water chiller package were obtained from manufacturers' catalogs for the specific unit installed in the building.

The chiller part-load curve is shown in Figure 7; the values used for peak electrical demand on the chiller, condenser, and supply fan were determined from measured data. The fan system operating parameters as input to the BLAST simulation are shown in Table 2.

Computer Simulation -- Dental Clinic

Actual weather data gathered by the Army's energy monitoring project were obtained for the period 1 June through 6 July 1978, and a BLAST simulation of the clinic was performed for this period. The simulation predicted the hourly total, internal building, fan system, and chiller package electrical consumption. No gas consumption was predicted since the hot water boiler was off during the simulation period. Weather data from 6 to 26 July 1978 were not available due to instrumentation malfunction.

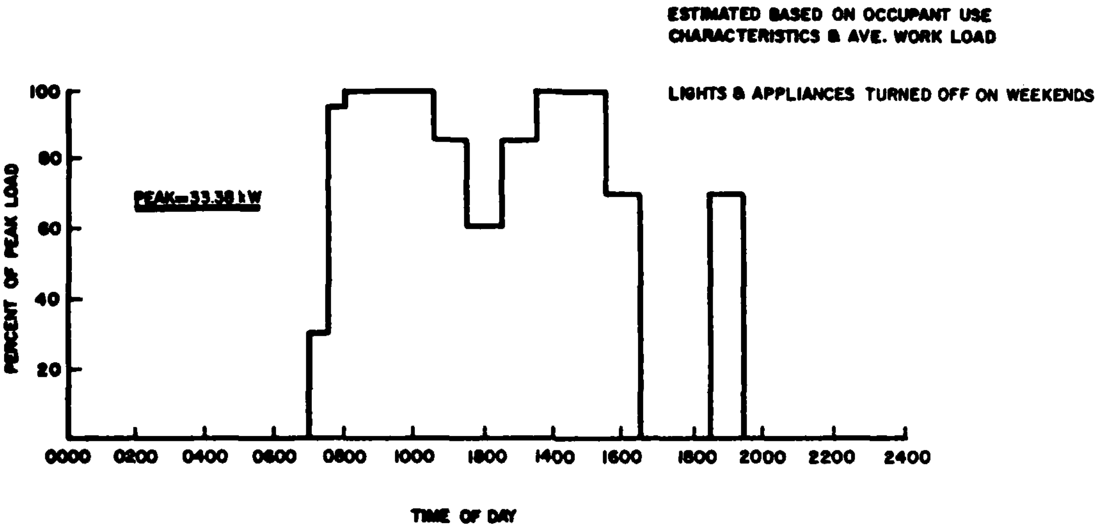

Figure 5. Internal electric load profile -- dental clinic (includes lights and appliances, weekdays only).

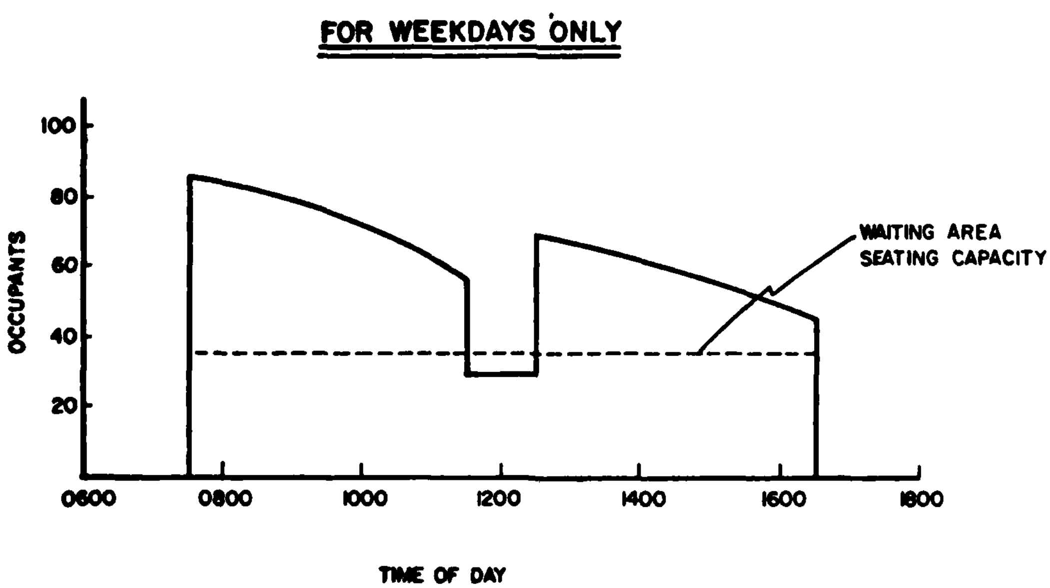

Figure 6. Occupancy profile -- dental clinic (includes patient waiting area and employees.

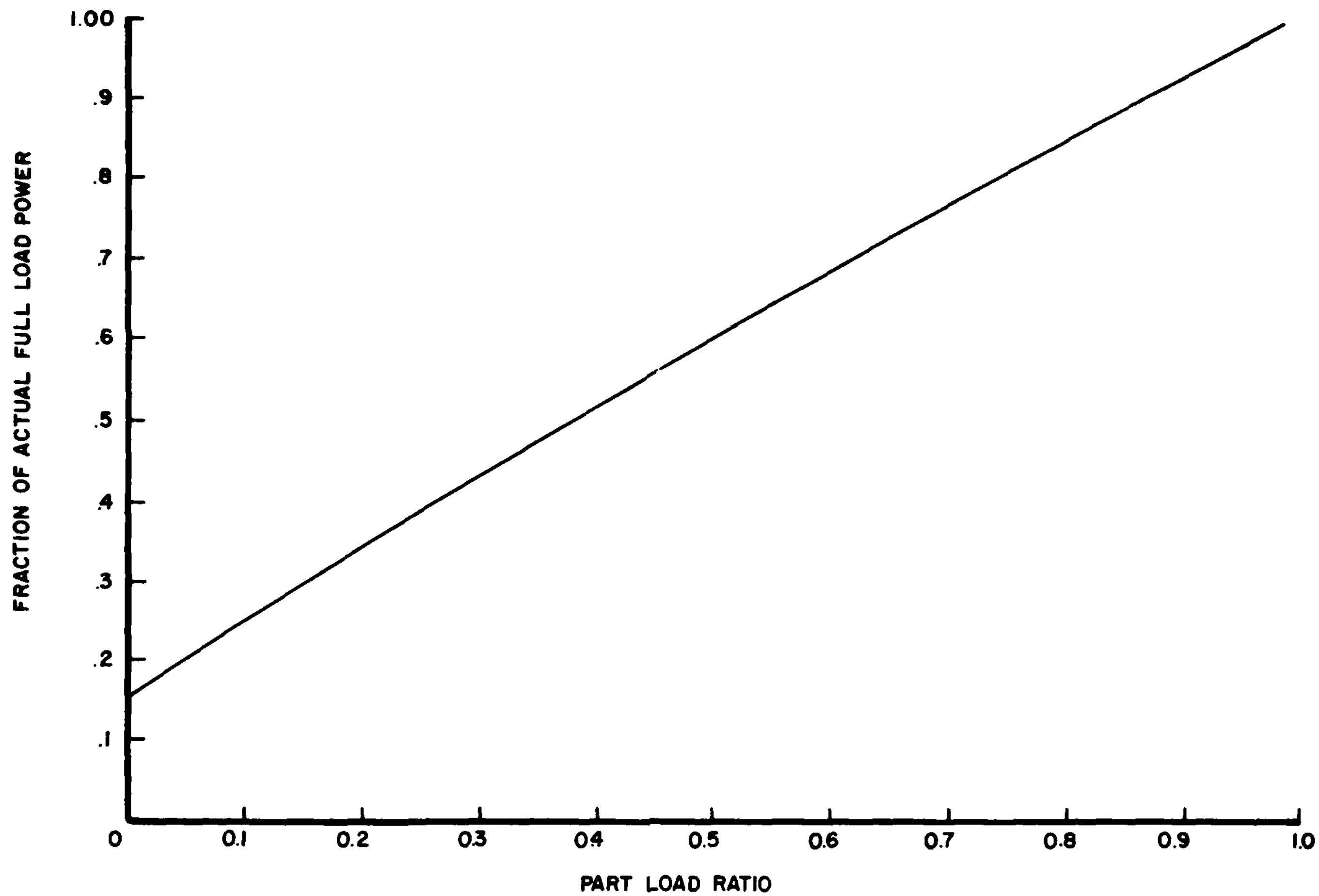

Figure 7. Chiller package part-load power consumption -- dental clinic.

Table 2

Fan System Parameters -- Dental Clinic

Type system = multizone

System operation = continuous

<u>Seasonal Component Schedules</u>

Heating coil on: 1 October; off: 31 March
Cooling coil on: 1 January; off: 31 December

Mixed air control = fixed amount
Fixed outside air volume = 1.942 m^3/s

Hot deck control = outside air control
Hot deck throttling range = 4.0 ^{o}C
Hot deck control schedule = (48.89 at -12.22, 26.67 at 21.11) ^{o}C

Heating coil capacity = 1000 kW
Heating coil energy supply = hot water

Cold deck control = fixed set point
Cold deck throttling range = 2.77 ^{o}C
Cold deck fixed temperature = 15.55 ^{o}C

Zone Number	Zone Supply Air Volume (m^3/s)	Zone Exhaust Air Volume (m^3/s)
1	0.842	0.4719
2	0.1916	0.0
3	0.9486	0.0
4	0.3592	0.2832
5	0.2369	0.0
6	0.3931	0.0
7	0.4172	0.0
8	0.3912	0.0
9	1.060	0.0
10	0.9934	0.0

Total design supply air volume = 5.883 m^3/s

Comparison -- Dental Clinic

For the period 1 June to 6 July 1978, both hourly weather data and data on the building's total electric consumption were available from the Army's energy monitoring project; hourly and total consumption comparisons between measured total electrical consumption and predicted total electrical consumption were made (Table 3). For the period 25 June to 1 July 1978, hourly electrical data for the building's internal electric consumption and the chiller electric consumption were also available, and hourly comparisons were made between this measured data and the predicted data (Figures 8 and 9).

Comparison results in Table 3 show that BLAST-predicted total building electrical consumption is 7.2 percent lower than the measured total building electrical consumption for the entire simulation period. In this case, R* = 0.87, a relatively good correlation. A plot for 1 week of BLAST-predicted and actual measured total building electric data is shown in Figure 8. Table 3 also shows hourly statistics for BLAST-predicted vs actual measured data, including the average difference for each hour, the average percent difference for each hour, and the average absolute difference for each hour. The variance and standard deviation for each difference is shown. (The formulas for obtaining these statistics are given in the Appendix.)

The results of the dental clinic simulation indicate that model parameters used for the simulation did not accurately reflect the clinic's operation. To determine the input parameter(s) in error, a detailed analysis was made of individual portions of the clinic's electrical demand from 25 June to 1 July 1978, using measured data.

It was determined that the simulation's major inaccuracy was the internal building electrical consumption prediction, which was 40 percent below the measured value. This large difference appeared to be caused by the internal building electrical profile used for the simulation; this profile defined zero consumption for nights and weekends (Figure 5). Analysis of actual measured data for internal building electrical consumption clearly showed that this profile was wrong, since the clinic has a minimum baseline electrical load; i.e., vending machines, drinking fountains, refrigerators, emergency and security lighting, and thermostatically controlled, continuously operating laboratory equipment such as dental ovens. The correlation coefficient of 0.87, however, indicates that the simulated profile tended to follow the same shape as the measured consumption profile.

The BLAST simulation also produced a value for chiller package electrical consumption that was 14.6 percent higher than the measured data. In this case, the correlation coefficient (0.78) is somewhat less than for the other individual electrical loads. Figure 9 shows the

*The correlation coefficient (R) is an indicator of how well the shape of the prediction curve follows the shape of the measured curve.

Table 3

Dental Clinic (Simulation 1)

	Measured (kWh)	Predicted (kWh)	% Difference
Total Building Electrical			
1 June 0000 to 6 July 0900	44,687	41,462	7.2
Internal Building Electrical			
25 June 0000 to 1800 and 26 June 0700 to 1 July 0900	2,345	1,401	40.3
Chiller Electrical			
25 June 0000 to 1800 and 26 June 0200 to 1 July 0900	4,597	5,271	-14.6

Statistics (hourly)*	Total Bldg.	Internal Bldg.	Chiller
R**	0.87	0.87	0.78
DIFFAVE (kW)	5.28	5.91	-1.07
DIFFVAR	116.31	47.33	116.58
DIFFSTD	10.78	6.88	10.79
PERAVE	11.99	55.40	-0.83
PERVAR	511.96	3,229.20	999.14
PERSTD	22.63	56.86	31.51
DABSAVE (kW)	10.3	7.41	9.13
DABSVAR	41.67	27.16	33.69
DABSSTD	6.45	5.21	5.81

* See Appendix for definition for statistics.
**Correlation coefficient

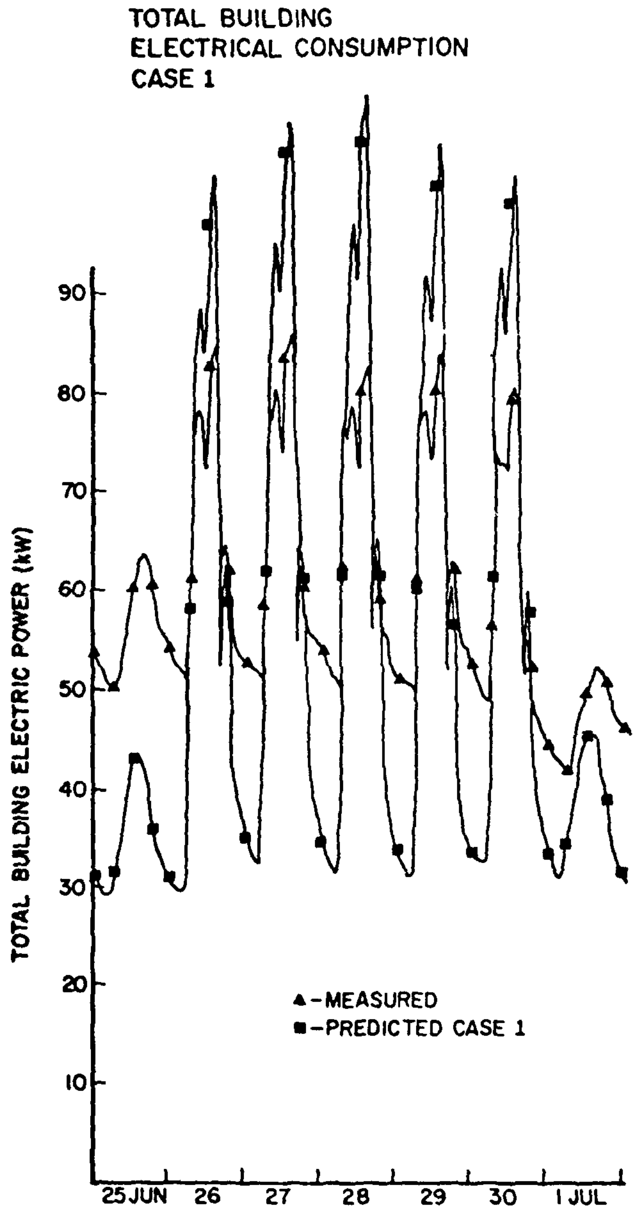

Figure 8. Total building electric consumption -- dental clinic.

curve of measured vs predicted values from 25 June to 1 July 1978. Apparently, the major reason for BLAST's inaccurate prediction was a simulated design full-load power ratio that was too high; actual data showed a design full-power ratio 13 percent less than that used in the simulation.

The simulation resulted in a fair agreement (7.2 percent) between predicted and measured electrical energy consumption for the total building; however, this agreement is caused by cancelling errors resulting from a low prediction for internal electrical consumption and a high prediction for chiller electrical consumption. These types of cancelling errors can result when a building is modeled on the BLAST program (or other energy analysis programs) without properly determining the building's total hourly electrical consumption.

Simulation Adjustments -- Dental Clinic

A new internal building electrical profile was developed using the baseline (continuous) load indicated by the measured data (Figure 10). In addition, a new value for chiller design full-load power ratio, based on measured data, was determined to provide a more correct peak chiller power consumption.

Discussion -- Dental Clinic

After adjusting the BLAST input to correct errors identified in the first dental clinic simulation, a second simulation was performed for the period 1 June to 6 July 1978. The results of this revised simulation are shown in Table 4. Note that the revised BLAST prediction for total electrical consumption for the entire simulation period is 12 percent higher than the measured electrical consumption. The correlation coefficient for the measured vs predicted data is 0.87. Figure 11 shows a plot of predicted and measured total electrical consumption for the revised simulation for the week of 25 June to 1 July 1978.

To determine why measured and predicted total electrical consumption data disagreed, analyses were performed on individual electrical load components. Results of these analyses for the internal building electrical consumption data and the chiller package electrical consumption data are shown in Table 4. A plot of predicted and actual chiller electrical consumption data for the week of 25 June to 1 July 1978 is shown in Figure 12.

The results of the detailed analyses of the internal building electrical consumption prediction indicate that the adjusted profile predicts a consumption within 10 percent of the measured data and has a correlation coefficient of 0.90. The results also indicate that the revised internal building electrical consumption profile consistently overpredicts the electrical consumption.

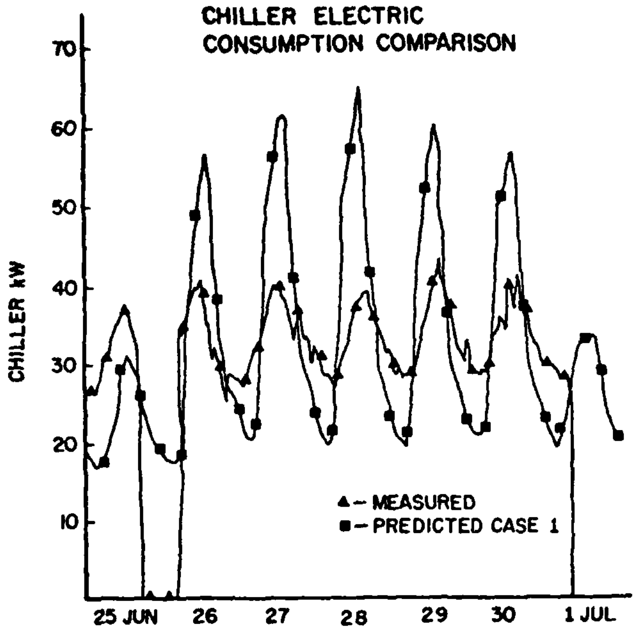

Figure 9. Chiller consumption - dental clinic (Simulation 1).

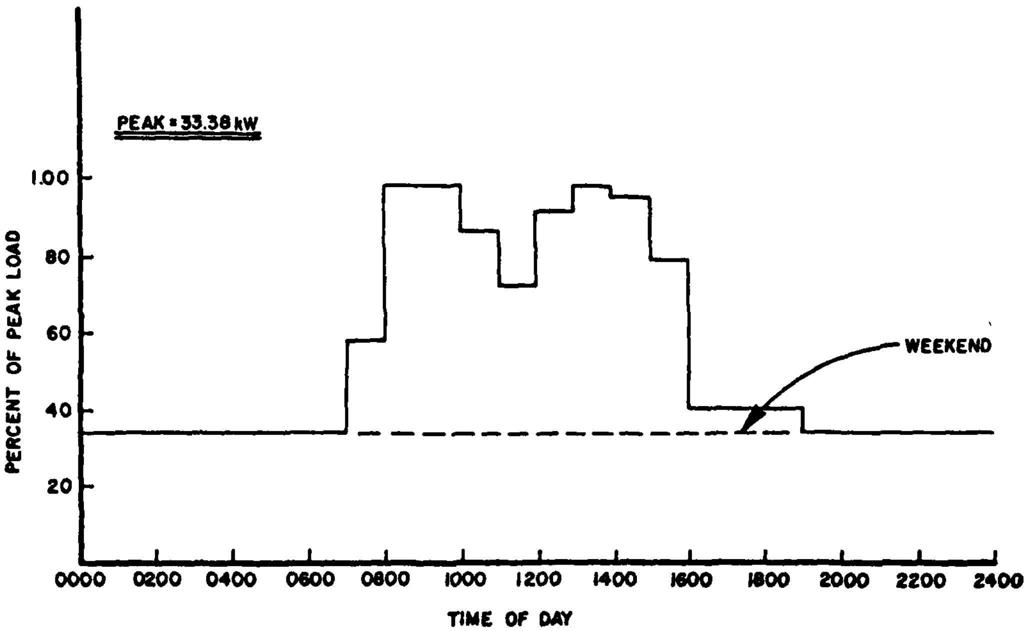

Figure 10. New internal load profile -- dental clinic.

Table 4

Dental Clinic (Simulation 2)

	Measured (kWh)	Predicted (kWh)	% Difference
Total Building Electrical			
1 June 0000 to 6 July 0900	44,687	50,091	-12.1
Internal Building Electrical			
25 June 0000 to 1800 and 26 June 0700 to 1 July 0900	2,345	2,581	-10.1
Chiller Electrical			
25 June 0000 to 1800 and 26 June 0700 to 1 July 0900	4,597	5,038	-9.6

Statistics (hourly)*	Total Bldg.	Internal Bldg.	Chiller
R**	0.87	0.90	0.79
DIFFAV (kW)	-5.87	-1.12	-1.25
DIFFVAR	55.90	39.20	
DIFFSTD	7.43	4.36	6.26
PERAVE	-15.76	-46.03	-2.79
PERVAR	620.75	17,135.00	327.14
PERSTD	24.91	130.90	18.09
DABSAVE (kW)	7.30	3.44	4.97
DABSR	36.29	8.37	15.91
DABSSTD	6.02	2.89	3.99

* See Appendix for definition of statistics.
**Correlation coefficient

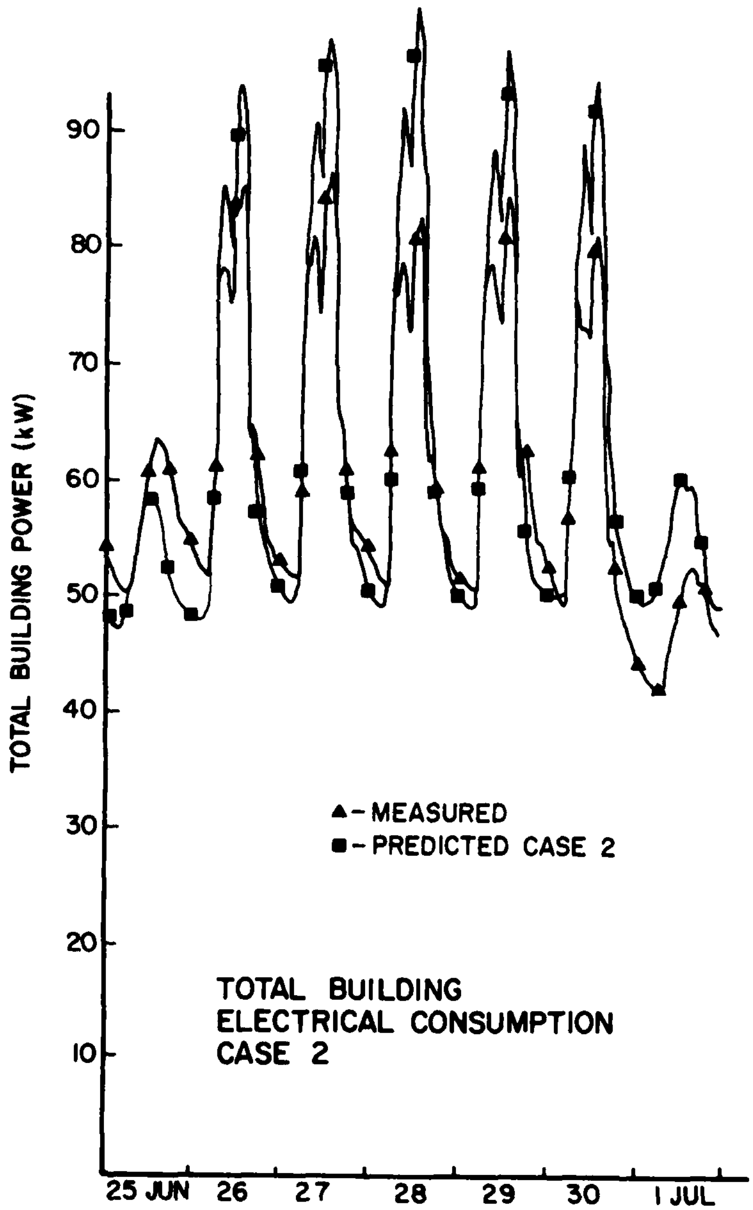

Figure 11. Total building power consumption -- dental clinic (Simulation 2).

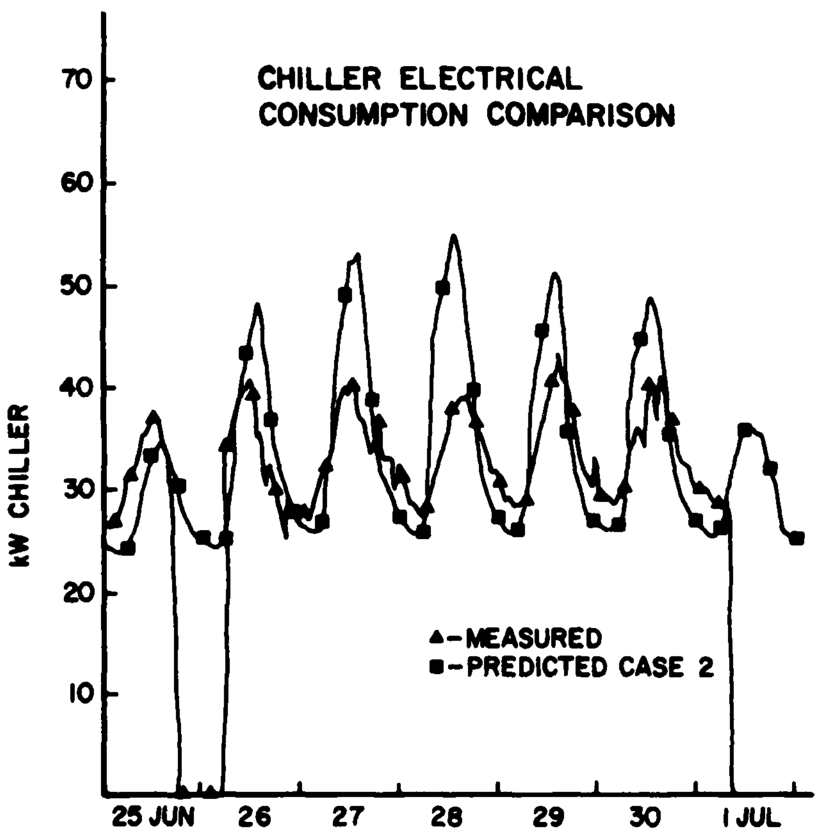

Figure 12. Chiller consumption -- dental clinic (Simulation 2).

The results of the detailed analyses of the revised chiller package electrical consumption prediction indicate agreement within 10 percent of the measured data; the correlation coefficient is 0.79. The revised chiller input predicts the low part-load operation almost exactly, but consistently overpredicts during the high part-load operating conditions of the chiller package (Figure 12).

Summary -- Dental Clinic

A comparison of the results of the original simulation with the revised simulation shows that on an individual component basis, the revised simulation is in every case better than the original. However, the total electrical consumption prediction for the original simulation is somewhat better than the revised one. This is primarily caused by the effects of cancelling errors. As the results show, the original model consistently underpredicts the internal building electrical consumption and overpredicts the chiller package's electrical consumption, while the revised model slightly overpredicts both.

The results also indicate that improvements could be made in the input used to describe the dental clinic's chiller package performance. The default full-load power ratio adjustment curve as input to the BLAST program could be revised to more accurately reflect actual chiller operation; also, the part-load ratio curve could be modified at the higher load conditions to more accurately reflect actual consumption. (It would be difficult to accurately determine these parameters, since the system did not operate at full load during the simulation/monitoring period.) The internal load profile used to predict internal building electrical loads could be revised to improve the accuracy of the BLAST prediction. Analysis of the measured internal electrical consumption data, however, indicates that the baseline internal building electrical consumption for nights and weekends fluctuates irregularly. Thus, it would be very difficult to accurately predict a single profile for the clinic's internal electrical consumption. Because of the size of the facility, even small fluctuations in this demand can cause relatively large errors in predicted vs measured data.

Additional revisions could be made to the simulation input to achieve more accurate predictions. However, this study indicates that if an exact profile is available, an accurate prediction of building energy consumption can be achieved using the BLAST program.

Building Description -- Battalion Headquarters and Classroom Building

The first floor of the battalion headquarters and classroom building was divided into nine simulation zones which corresponded to the seven zones served by the building's multizone air handler and the two zones served by the building's unit heaters (Figure 3). The basement floor of the facility was modeled as a single zone served by a unit

ventilator system (as shown in the as-built drawings). Zone geometries and construction details of the walls, roof, floors, and ceiling were determined from the construction drawings. The electrical load profiles for the building and the peak building internal electrical demand were supplied by a contractor (Figure 13). Peak electrical demand for each zone was estimated from a disaggregation of the peak internal building electrical demand. Building occupancy was determined from occupant questionnaires. The occupancy profile for the building was estimated by the contractor (Figure 14). Zone peak occupancy (estimated from building use patterns), zone thermostat settings, and control profiles were determined from the contractor-supplied data.

Mechanical System -- Battalion Headquarters and Classroom Building

Information about the fan system was obtained from construction drawings, the HVAC control diagrams, control specifications, and contractor-measured data. Because this facility is served by a large central boiler-chiller plant serving many buildings, a mechanical plant was not simulated.

Computer Simulation -- Battalion Headquarters and Classroom Building

A BLAST simulation of the battalion headquarters and classroom building was performed for the period 1 August to 6 September 1978 using actual weather data. The hourly data available from the simulation included total building boundary, internal building, and fan system electrical consumption. BLAST also predicted the building's hot and chilled water demands.

Comparison -- Battalion Headquarters and Classroom Building

After the BLAST simulation was completed, continuous electrical energy-use data were obtained from the Army's energy monitoring project for the simulation period, and a comparison made between actual measured and BLAST-predicted electrical consumption data. The results, in Table 5, show that the predicted total building electrical consumption is 49.6 percent higher than the measured total building electrical consumption for the entire simulation period. (Hourly statistics for the week of 6 to 12 August 1979 are also shown in Table 5.) The correlation coefficient for this simulation was 0.70, indicating a poor relationship between predicted and measured data.

Since this building has no chiller plant, and since fans and pumps ran continuously and consumed constant amounts of power, the major inaccuracy in the simulation was its prediction of the internal building electrical demand. The contractor-supplied profile defines the same electrical consumption for weekends as for weekdays (Figure 13).

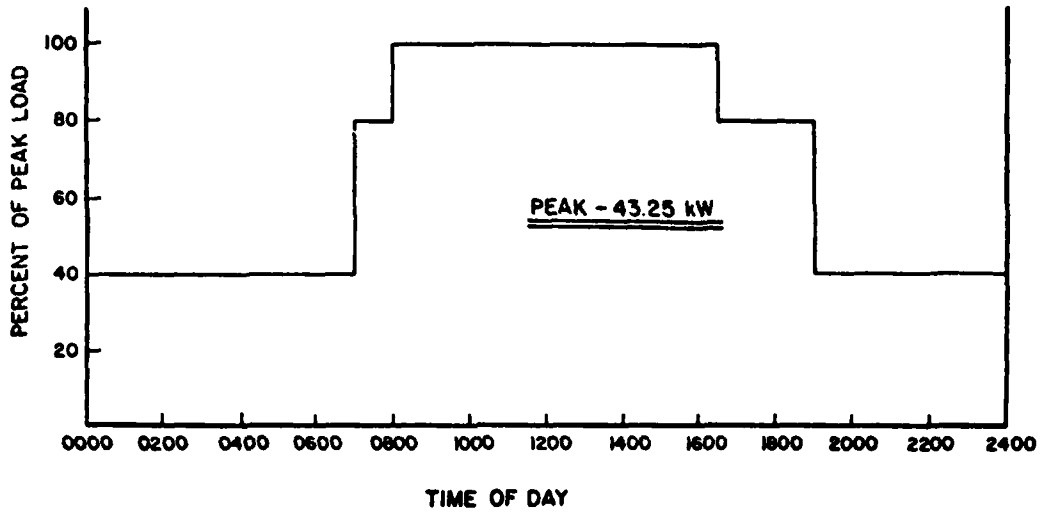

Figure 13. Internal load profile -- battalion headquarters and classroom building (includes lights and appliances).

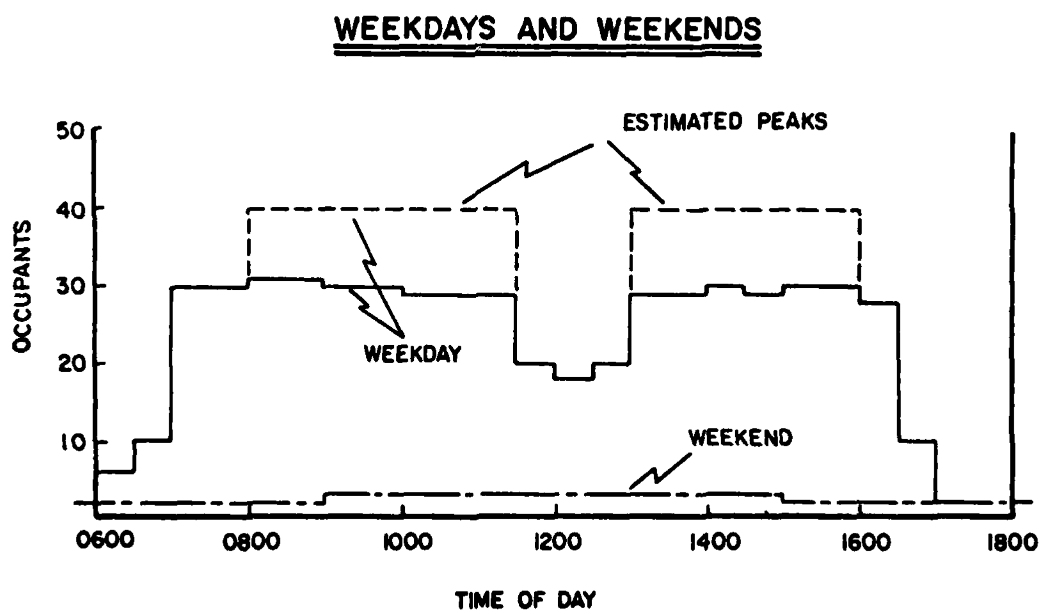

Figure 14. Occupancy profile -- battalion headquar'ers and classroom building (entire building, excluding classroom use).

Table 5

Battalion Headquarters and Classroom Building (Simulation 1)

	Measured (kWh)	Predicted (kWh)	% Difference
Total Building Electrical			
1 August to 6 September 1978	20,952.9	31,340	49.6

Statistics (hourly)* for 6 August - 12 August 1978	Total Building Electrical
R**	0.70
DIFFAVE (kWh)	-12.73
DIFFVAR	79.49
DIFFSTD	8.9
PERAVE	-57.3
PERVAR	1,936.4
PERSTD	44.0
DABSAVE	12.756
DABSVAR	78.72
DABSSTD	8.872

* See Appendix for definition of statistics.
**Correlation coefficient

Analysis of measured data showed that this profile was in error for both weekend and nighttime periods.

Measured hot and chilled water consumption data were not available from the Army's energy monitoring project because of instrumentation failure; therefore, a hot and chilled water consumption comparison could not be made for the simulation period.

Simulation Adjustments -- Battalion Headquarters and Classroom Building

The BLAST simulation of the battalion headquarters and classroom building was adjusted to correct the internal building electrical demand profile, using measured data gathered from 6 to 12 August 1978 (Figure 15).

Discussion -- Battalion Headquarters and Classroom Building

After revising the BLAST input for the battalion headquarters and classroom building, the simulation was repeated for the period of 1 August to 6 September 1978. The results of the revised simulation are shown in Table 6. The revised prediction for total building electrical consumption for the entire simulation period is 5.2 percent lower than the measured total building electrical consumption. The correlation coefficient for the week of 6 to 12 August 1978 is 0.93.

Summary -- Battalion Headquarters and Classroom Building

A comparison of the results of the original and revised simulations indicates that the revised simulation is much more accurate. Because of the good agreement of the revised prediction with the measured data, further input revision would appear unnecessary. The small disagreement is caused by small fluctuations in building use patterns. Therefore, it would be very difficult to determine a more accurate profile of internal building electric demand.

General Results

The results of simulations conducted for the dental clinic and the battalion headquarters and classroom building both compare measured data to BLAST-predicted internal and chiller electrical consumption data. Although the simulations also predicted other energy data, such as chilled and hot water demands and gas consumption, these data could not be compared to measured data because equipment used in the Army energy monitoring project malfunctioned during periods covered by the BLAST simulations. (A winter simulation was not performed for either building because of the failure of weather data recording equipment used for the energy monitoring project.)

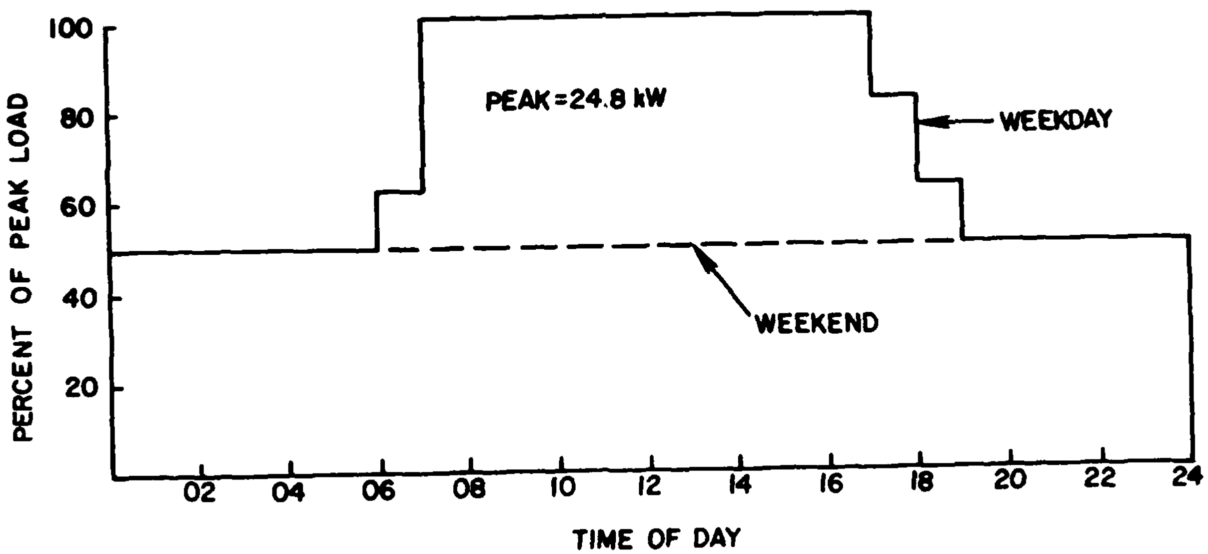

Figure 15. New internal load profile -- battalion headquarters and classroom building (includes lights and appliances).

Table 6

Battalion Headquarters and Classroom Building (Simulation 2)

	Measured (kWh)	Predicted (kWh)	% Difference
Total Building Electrical			
1 August to 6 September 1978	20,952.9	19,910	-5.24

Statistics (hourly)* for 6 August -12 August 1978	Total Building Electrical
R**	0.93
DIFFAVE	-0.89
DIFFVAR	5.06
DIFFSTD	2.25
PERAVE	-1.16
PERVAR	78.71
PERSTD	8.87
DABSAVE	1.561
DABSVAR	2.619
DABSSTD	1.618

* See Appendix for definition of statistics.
**Correlation coefficient

4 CONCLUSIONS

1. The BLAST energy analysis computer program was used to successfully predict the internal electrical and chiller package electrical consumption of buildings (±10 percent) when accurate input was made to the program; i.e., values for building geometry, materials, schedules, controls, and HVAC systems had to be precise and consistent.

2. An accurate internal electrical profile for the building was difficult to define because of daily fluctuations in electrical usage. Users of energy analysis programs must insure consideration of all internal electrical devices and determine hourly usage and peak demand for weekdays and weekends before inputting a building schedule to the BLAST energy analysis program.

3. To verify an energy analysis program such as BLAST, accurate, concurrent hourly measurements of weather data, building energy-use profiles, occupant patterns, and equipment operating parameters must be obtained.

4. The chiller predicted vs actual curve (Figure 12) confirms the validity of modeling cooling components on an hourly time step. The chiller simulation actually models the average performance of the component over the hour, while the real chiller cycles during a much smaller time step. Predicted and actual curves will show modeling validity and its sensitivity to changes in part-load ratios and full-load power of the chiller package.

APPENDIX:
STATISTICAL FORMULAS

$$DIFFAVE = \frac{\Sigma D}{N} \qquad PERAVE = \frac{\Sigma P}{N} \qquad DABSAVE = \frac{\Sigma |D|}{N}$$

$$DIFFVAR = \frac{N\Sigma D^2 - (\Sigma D)^2}{N\ (N-1)} \qquad PERVAR = \frac{N\Sigma P^2 - (\Sigma P)^2}{N\ (N-1)} \qquad DABSVAR = \frac{N\Sigma D^2 - (\Sigma |D|)^2}{N(N-1)}$$

$$DIFFSTD = \sqrt{DIFFVAR} \qquad PERSTD = \sqrt{PERVAR} \qquad DABBSTD = \sqrt{DABSVAR}$$

where X = measured
Y = predicted
D = X-Y
N = number of observations
P = D divided by X times 100

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